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Bottom Backscattering Measured in the Adriatic Sea During the Littoral Warfare Advanced Development 00-3 Experiment

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Measurements of ocean bottom backscattering were performed at two shallow water sites (Site 2 and Site F) in the Adriatic Sea as part of the Littoral Warfare Advanced Development 00-3 Experiment. Bottom samples revealed a silty clay bottom at Site 2 and a silty sand bottom at Site F. Scattering strengths were obtained at 0.4 to 5 kHz as a function of mean grazing angle. For all measurements, the grazing angle dependence was fit adequately by assuming a dependence of scattering strength (dB) on the sine of the mean grazing angle: $\mu + 10 \log (\sin \theta)$. Bottom scattering strengths were low at the two sites. Scattering strengths at Site 2 were well fit using $\mu = -40$ to -45 dB at low frequencies (400 to 1000 Hz), and $\mu = -35$ to -40 dB at mid frequencies (2.5 to 5 kHz). Although expected to be higher, the LF scattering strengths at Site F fell between μ's of -40 and -50 dB.

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INTRODUCTION

The Littoral Warfare Advanced Development (LWAD) 00-3 experiment was conducted in the Adriatic Sea near Bari, Italy in October 2000. Bottom backscattering strength (BSS) in the 0.4 to 5 kHz band was calculated at two shallow water sites using direct path measurements.

Bottom backscattering measurements have been performed during seven previous LWAD experiments: Focused Technology Experiment 96-2 (FTE 96-2), Focused Technology Experiment 97-2 (FTE 97-2), System Concept Validation 97 (SCV-97), LWAD Experiment 98-2 (LWAD 98-2), LWAD Experiment 98-4 (LWAD 98-4), LWAD Experiment 99-1 (LWAD 99-1) and LWAD Experiment 99-3 (LWAD 99-3). The FTE 96-2, SCV-97 and LWAD 98-4 backscattering measurements were made off the Carolina coast and the results appear in [1,2,3]. The FTE 97-2, LWAD 98-2 and LWAD 99-1 measurements were made off the western coast of Florida and the results are reported in [4,5,6]. The LWAD 99-3 measurements were made off the coast of Oregon and appear in [7].

This report presents a summary of the LWAD 00-3 data collection and analysis approach. Following this discussion, BSS results are presented for frequencies from 0.4 and 5 kHz with a comparison to empirical model curves.

TEST OPERATIONS

The LWAD 00-3, direct-path bottom scattering tests were conducted in shallow water in the Adriatic Sea in October 2000. The measurements were made in two frequency bands (400-1000 Hz and 2500-5000 Hz), each using a vertical line array receiver and a transducer deployed on a single cable from the research vessel (R/V) *NORTHERN HORIZON*.

Test Location

Bottom scattering measurements were conducted while the R/V *NORTHERN HORIZON* was anchored at Site 2 (location: 41-44.5 N 16-39.6 E, approximately 30 nm northeast of Bari, Italy). The water depth at this site was 97 m. A bottom sample taken at Site 2 revealed a silty-clay bottom. Bottom scattering measurements were also conducted while drifting at Site F (location: 41-42.7 N 16-50.8 E, approximately 8.6 nm east of Site 2). The water depth at this site was 147 m. A bottom sample taken at the drifting site revealed a silty-sand bottom.

Measurement Overview

Receiver Characteristics. A vertical line array (VLA) was used with two apertures: a low-frequency (LF) aperture consisting of 16 elements uniformly spaced at 30 inches (0.76 m); and a mid-frequency (MF) aperture consisting of 16 elements uniformly spaced at 6 inches (0.15 m). The LF aperture received acoustic data in the 400- to 1000-Hz range, while the MF aperture received data in the 2.5- to 5-kHz range.

Source Characteristics. The LF source was a transducer (XF4) usable over 300 to 1000 Hz and resonant at 400 Hz. At Site 2, it gave a maximum source level of 190 dB re $(1\mu Pa)^2/Hz$ at 1 m at resonance (400 Hz) that decreased with increasing frequency to 176 dB at 1000 Hz. At Site F, the LF source levels were 2 dB higher.

The MF source was a transducer (F80) usable over 2.5 to 5 kHz. It gave a maximum source level of 182 dB re $(1\mu Pa)^2/Hz$ at 1 m at 5 kHz that decreased with decreasing frequency to 170 dB at 2.5 kHz.

Waveforms. For both the LF and MF measurements, the transmitted waveforms were 50-ms and 10-ms gated continuous wave (GCW) signals and 200-ms linear frequency modulated (LFM) signals. Twenty identical waveforms were transmitted separated by 15 s.

Measurement Geometries. For both scattering sites, the source was deployed at a depth of approximately 41 m, 4 m above the center of the MF aperture and 9 m above the center of the LF aperture. This produced a nearly monostatic measurement geometry.

DATA PROCESSING

The bottom reverberation from the signals was received[1] on the VLA. Seventeen, spatially-Hanned beams with cosine-spaced main response axes (MRAs) were formed for each of the two 16-phone apertures, with most of the usable returns coming from the downward-looking beams closest to broadside.

After beamforming, reverberation time series curves were obtained for individual GCW pings using spectral processing, while the individual LFM pings were matched filtered. For the GCW ping data, a uniform window matched to the signal duration was slid over the length of each beam time series with a 90%-overlap. The resulting time series segments were then Fourier transformed to obtain power spectra, with reverberation level computed by integrating the total received signal power over a narrow frequency band centered on the frequency of the transmitted signal. For each set of GCW and LFM data, the 20 individual pings were temporally aligned with respect to signal transmit time and then linearly averaged to produce a single reverberation curve for each beam.

A raytrace program was then used to calculate the geometric effects unique to each measurement: (1) calculating geometric spreading loss along each ray path, the transmission loss terms to and from the scattering patch were obtained; and (2) using the computed beam patterns and raytraces, the scattering patch areas were obtained.

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[1]The system calibration was computed to within 1 dB accuracy.

Finally, the average reverberation curves were combined with these geometric parameters and source level to solve the sonar equation for backscattering strength as a function of frequency, beam, and grazing angles:

$$BSS = RL - SL + TL_s + TL_r - 10 \log A \tag{1}$$

where BSS is the scattering strength in dB, RL is the measured reverberation level in dB re $(1\mu\text{Pa})^2/\text{Hz}$, SL is the source level in dB re $(1\mu\text{Pa})^2/\text{Hz}$ at 1 m, TL_s is the transmission loss from the source to the ensonified patch on the bottom in dB, TL_r is the transmission loss from the ensonified patch on the bottom to the receiver in dB, and A is the area of the ensonified patch in m^2.

MEASURED BACKSCATTERING STRENGTHS

Backscattering strengths as a function of mean grazing angle measured during LWAD 00-3 are shown in Figs. 1 to 23. In each case, BSS is plotted vs. the mean of the incident and scattered grazing angles. In each case, the plotted BSS values represent returns from beams whose MRAs spanned 60 to 83 degrees relative to bottom endfire (linearly averaged where appropriate, i.e. where there was grazing-angle overlap).

The standard deviations due to ping-to-ping variability within the sets of identical transmissions were ± 2 to 3 dB.

LF Site-2 Measurements

Figure 1 shows near-monostatic backscattering strengths measured at 400 Hz as a function of mean grazing angle at Site 2. The dashed curves represent $\mu + 10 \log(\sin \theta)$ dB for μ = -35, -40, and -45. These curves show that the grazing angle dependence can be fit adequately by assuming a first-power-law dependence of scattering strength on the sine of the mean grazing angle.

Figures 2 to 7 present near-monostatic backscattering results for the remaining six frequencies in the LF band (500, 600, 700, 800, 900, and 1000 Hz) at Site 2. The BSS data appear to increase with increasing frequency. Figure 8 overlays the BSS curves presented in Figs. 1 to 7 and shows that the BSS data cover mean grazing angles from 10 to 35 degrees and can be fit by $\mu + 10 \log(\sin \theta)$ using proportionality constants μ in the range of -40 to -45 dB.

MF Site-2 Measurements

Figures 9 to 14 present MF backscattering strengths (frequencies: 2.5, 3, 3.5, 4, 4.5, and 5 kHz) as a function of mean grazing angle. The dashed curves represent $\mu + 10 \log(\sin \theta)$ dB for μ = -35, -40, and -45. Figure 15 overlays the six BSS curves presented in Figs. 9 to 14. The near-monostatic MF backscattering strength measurements cover mean grazing angles of 4 to 36 degrees and can be fit by $\mu + 10 \log(\sin \theta)$ with μ in the range of -35 to -40 dB.

LF Site-F Measurements

Figures 16 to 22 present LF backscattering strengths (frequencies: 400, 500, 600, 700, 800, 900, and 1000 Hz) as a function of mean grazing angle at Site F. The dashed curves represent

$\mu + 10\log(\sin\theta)$ dB for $\mu = $ -40, -45, and -50. Figure 23 overlays the seven BSS curves presented in Figs. 16 to 22. The near-monostatic LF backscattering strength measurements cover mean grazing angles of 18 to 37 degrees and can be fit by $\mu + 10\log(\sin\theta)$ with μ in the range of -40 to -50 dB. Due to the presence of sand in the bottom at Site F, it was expected that backscattering strengths would be higher than those obtained at Site 2. However, the BSS results at Site F appear to be lower and display more variance. The fact that the measurement was conducted from a drifting vessel may have contributed to the variance.

SUMMARY

This report details the results of broadband direct-path measurements of bottom backscattering strength made during the Littoral Warfare Advanced Development 00-3 experiment, conducted in shallow water in the Adriatic Sea in October 2000. Backscattering strengths were measured over 0.4 to 4.5 kHz for mean grazing angles of 4 to 37 degrees at two shallow water sites (Site 2 and Site F).

All the acoustic data were fit adequately by assuming a first-power-law dependence of scattering strength on the sine of the mean grazing angle: $\mu + 10\log(\sin\theta)$ dB. Bottom scattering strengths were low at the two sites. At Site 2, scattering strengths for the LF band (400-1000 Hz) were well fit with μ's of -40 to -45 dB, while those in the MF band (2.5-5 kHz) were well fit with μ's of -35 to -40 dB. Although expected to be higher, the LF scattering strengths at Site F fell between μ's of -40 and -50 dB.

ACKNOWLEDGMENTS

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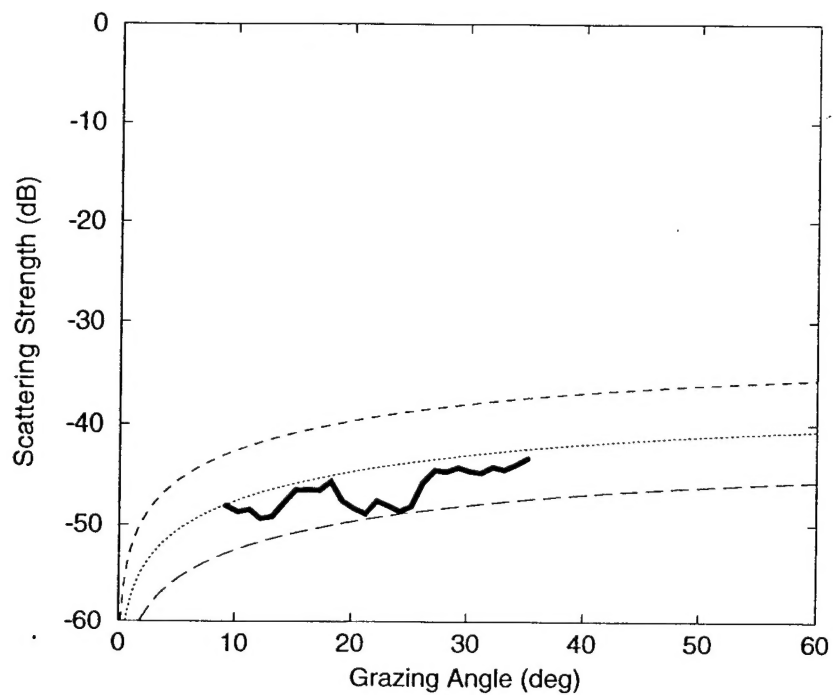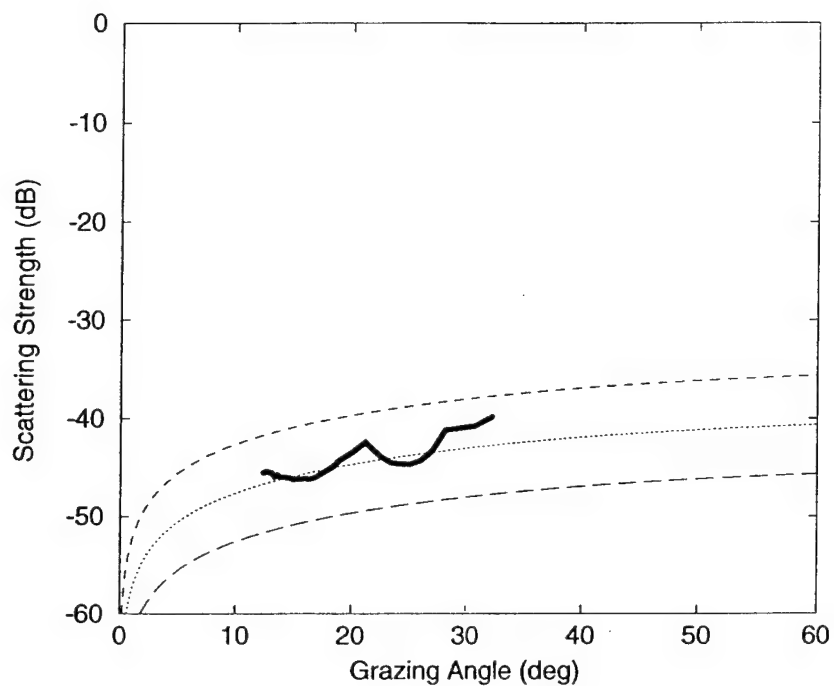
Fig. 1 — Bottom backscattering strength as a function of grazing angle for 400 Hz at Site 2. The dashed lines represent $\mu + 10\log(\sin\theta)$ for $\mu = $ -35, -40 and -45.
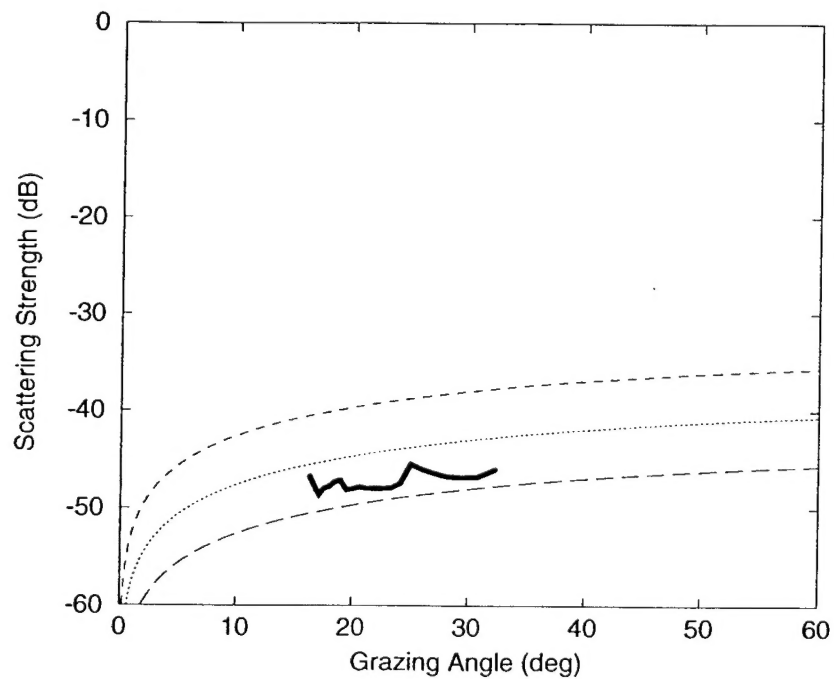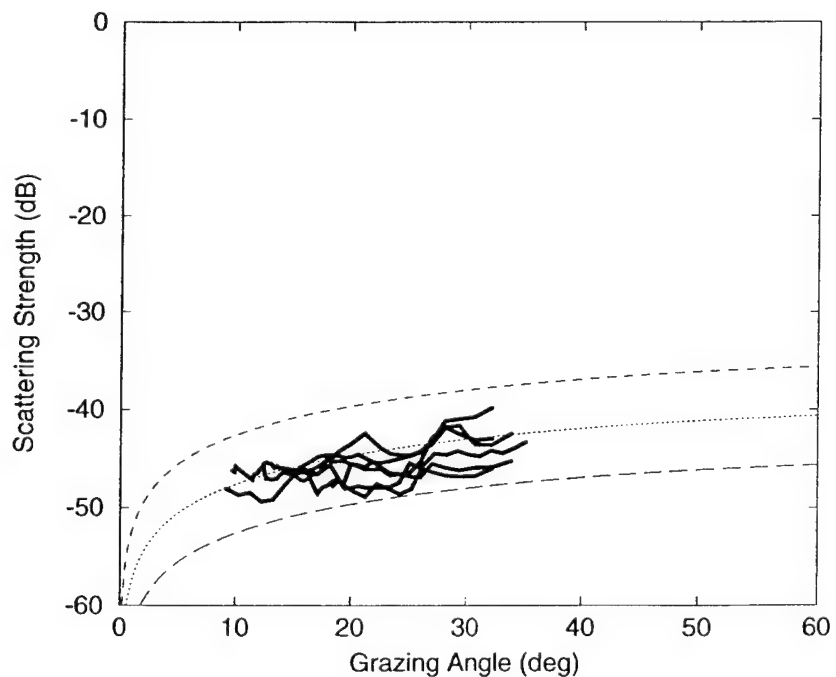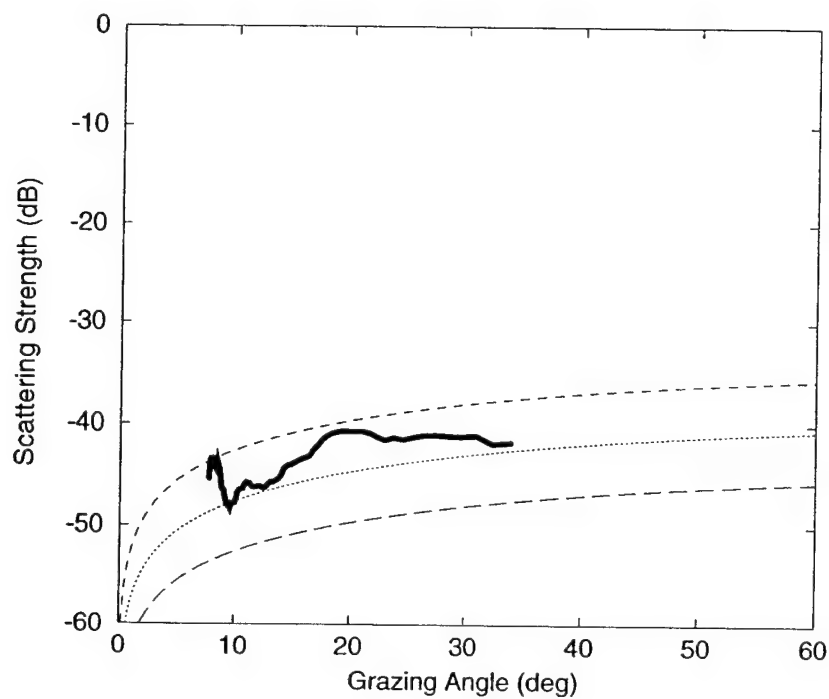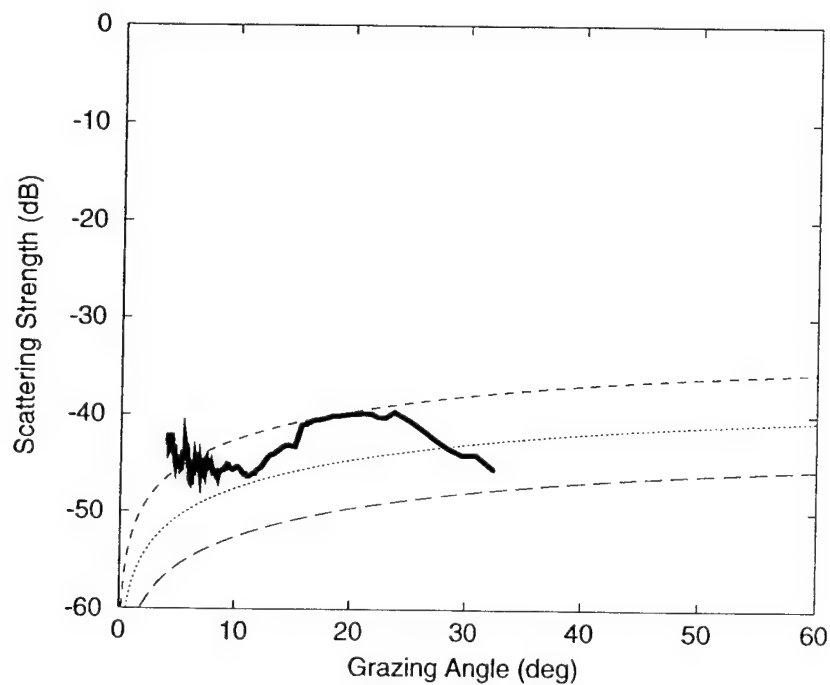

Fig. 2 — Bottom backscattering strength as a function of grazing angle for 500 Hz at Site 2. The dashed lines represent $\mu + 10\log(\sin\theta)$ for $\mu = $ -35, -40 and -45.
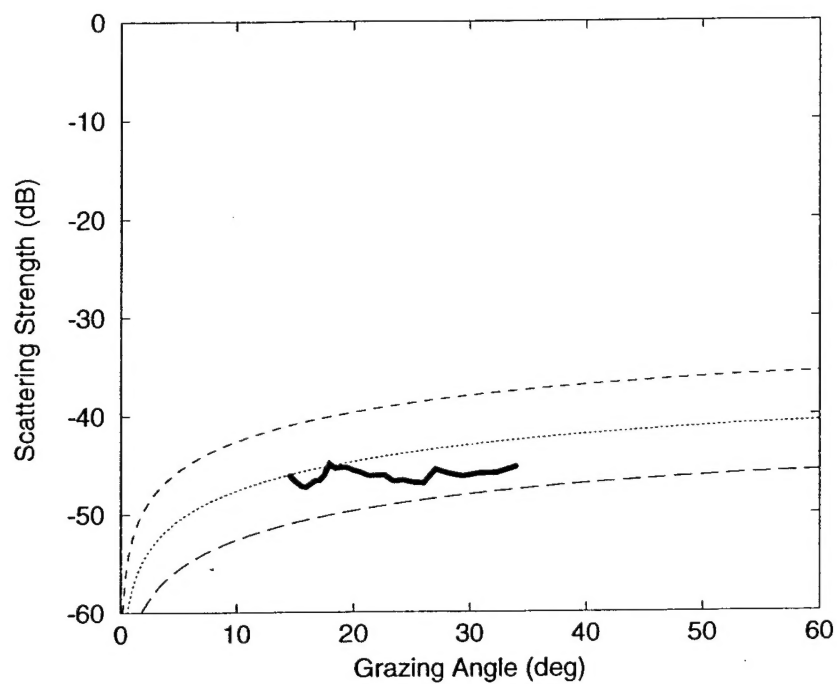
Fig. 3 — Bottom backscattering strength as a function of grazing angle for 600 Hz at Site 2. The dashed lines represent $\mu + 10\log(\sin\theta)$ for $\mu = $ -35, -40 and -45.
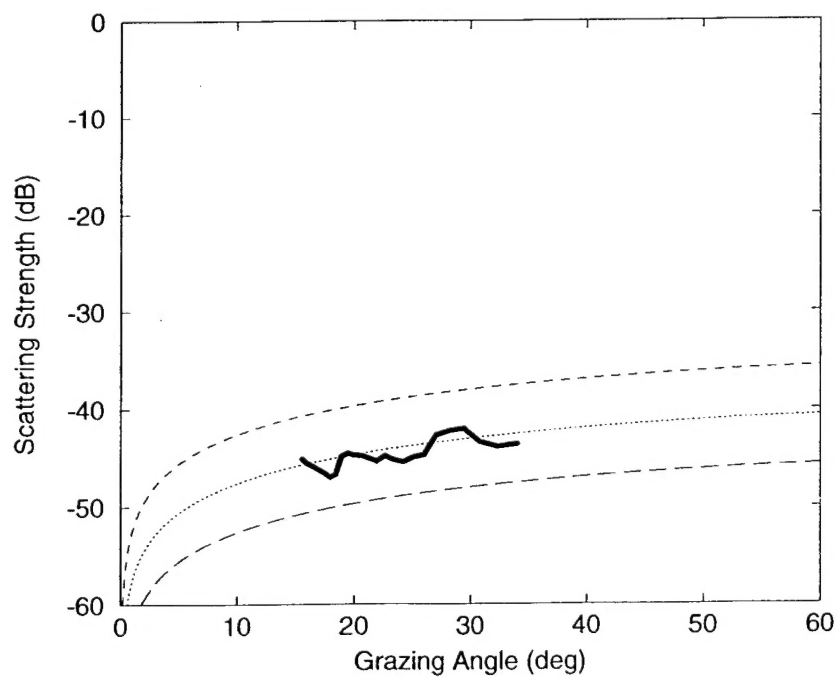
Fig. 4 — Bottom backscattering strength as a function of grazing angle for 700 Hz at Site 2. The dashed lines represent $\mu + 10\log(\sin\theta)$ for $\mu = $ -35, -40 and -45.
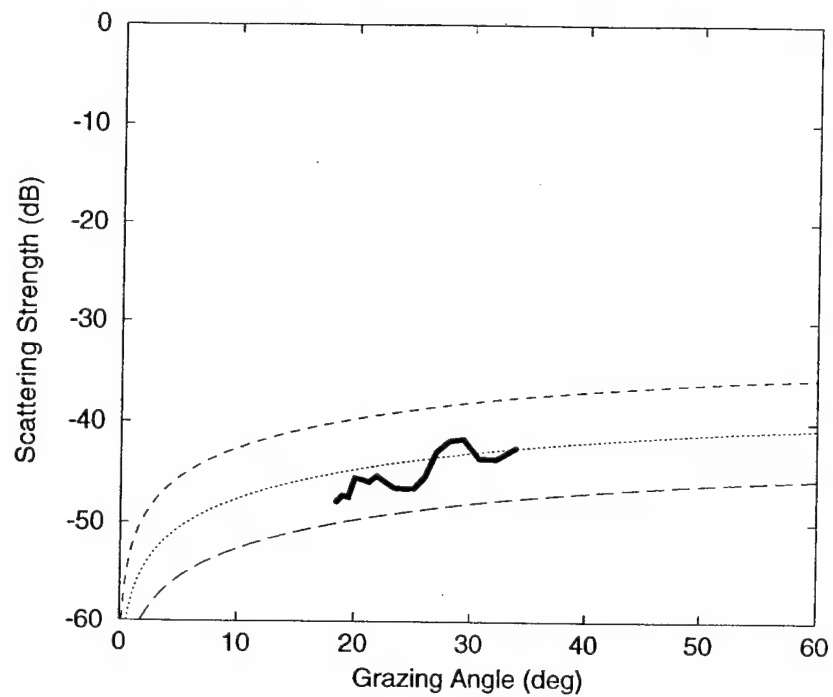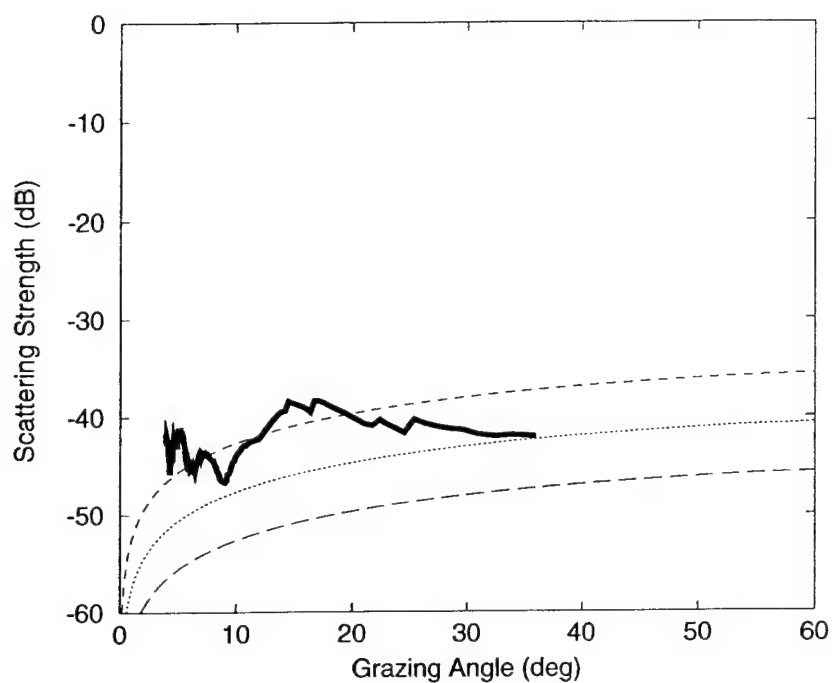
Fig. 5 — Bottom backscattering strength as a function of grazing angle for 800 Hz at Site 2. The dashed lines represent $\mu+10\log(\sin\theta)$ for $\mu = $ -35, -40 and -45.
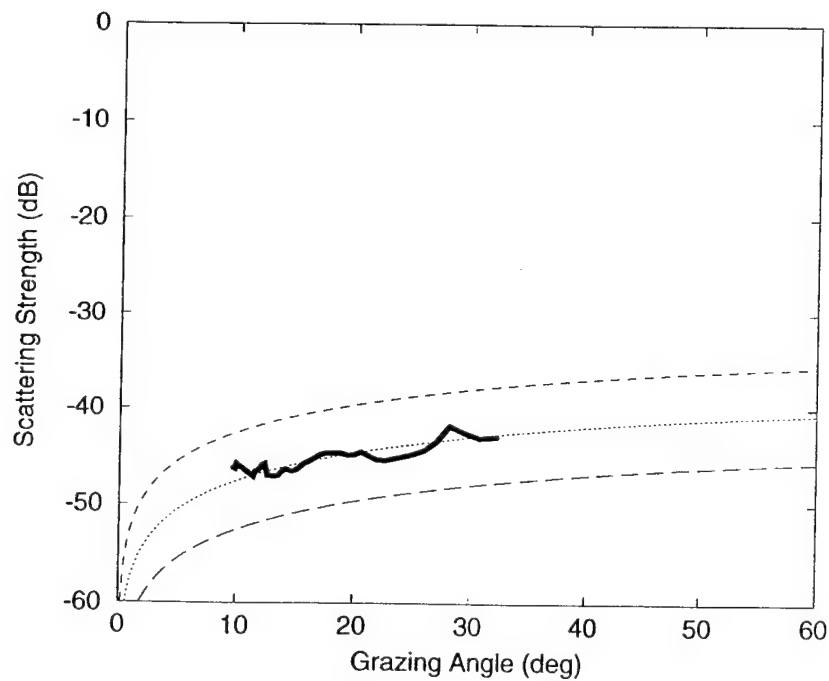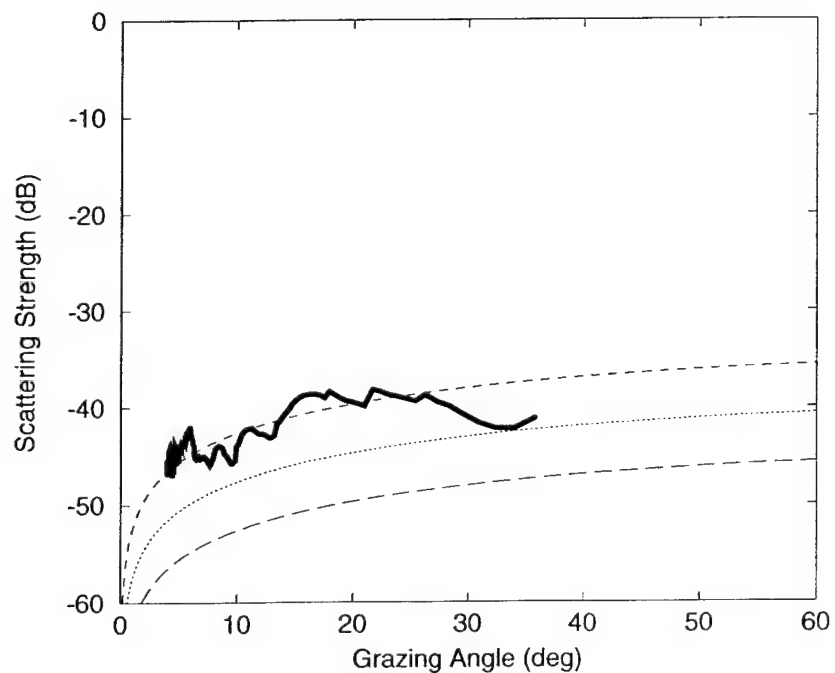

Fig. 6 — Bottom backscattering strength as a function of grazing angle for 900 Hz at Site 2. The dashed lines represent $\mu+10\log(\sin\theta)$ for $\mu = $ -35, -40 and -45.

Fig. 7 — Bottom backscattering strength as a function of grazing angle for 1000 Hz at Site 2. The dashed lines represent $\mu+10\log(\sin\theta)$ for $\mu=$ -35, -40 and -45.

Fig. 8 — Bottom backscattering strength as a function of grazing angle for all seven frequencies from the LF band (400, 500, 600, 700, 800, 900 and 1000 Hz) at Site 2. The dashed lines represent $\mu+10\log(\sin\theta)$ for $\mu=$ -35, -40 and -45.
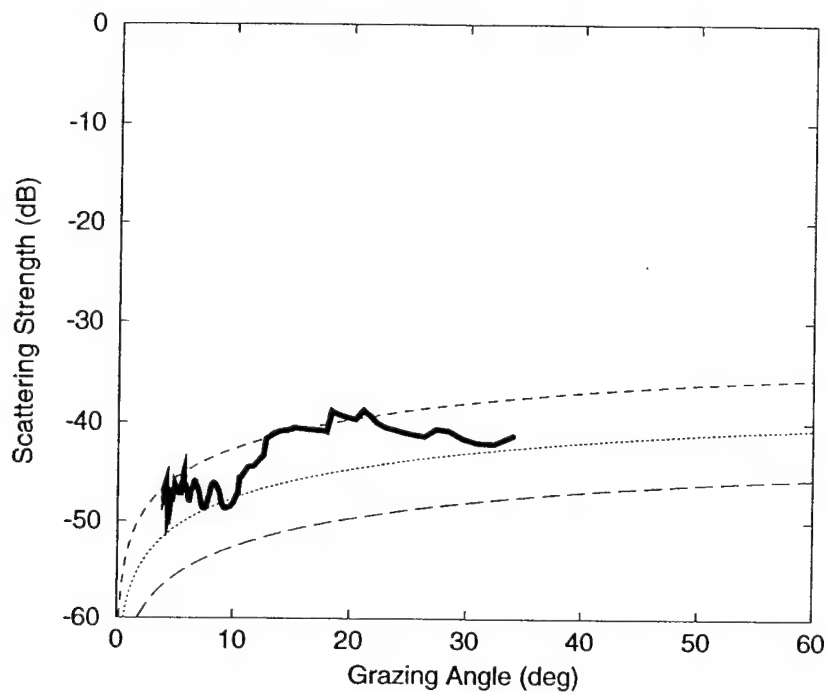
Fig. 9 — Bottom backscattering strength as a function of grazing angle for 2.5 kHz at Site 2. The dashed lines represent $\mu + 10 \log(\sin \theta)$ for $\mu = $ -35, -40 and -45.
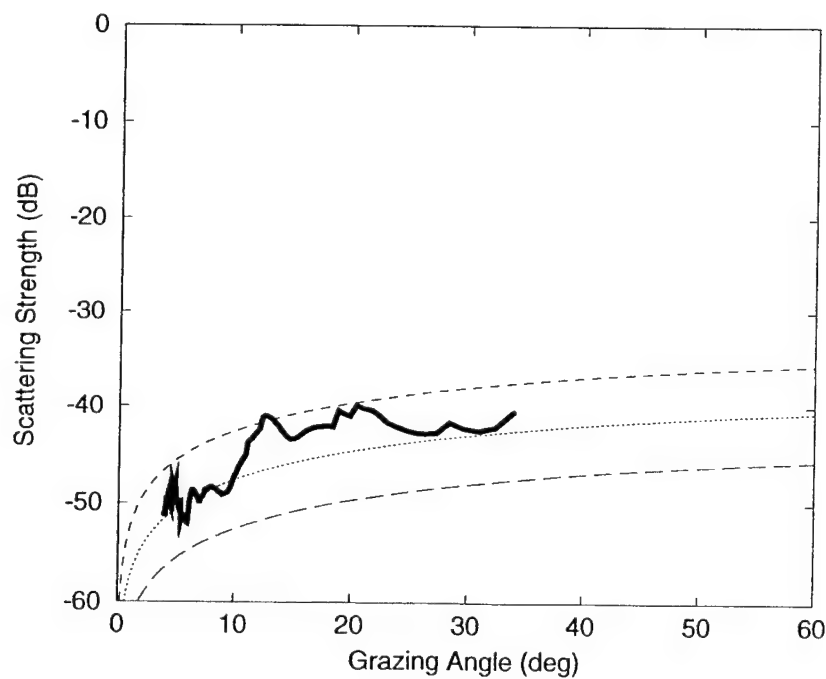

Fig. 10 — Bottom backscattering strength as a function of grazing angle for 3 kHz at Site 2. The dashed lines represent $\mu + 10 \log(\sin \theta)$ for $\mu = $ -35, -40 and -45.
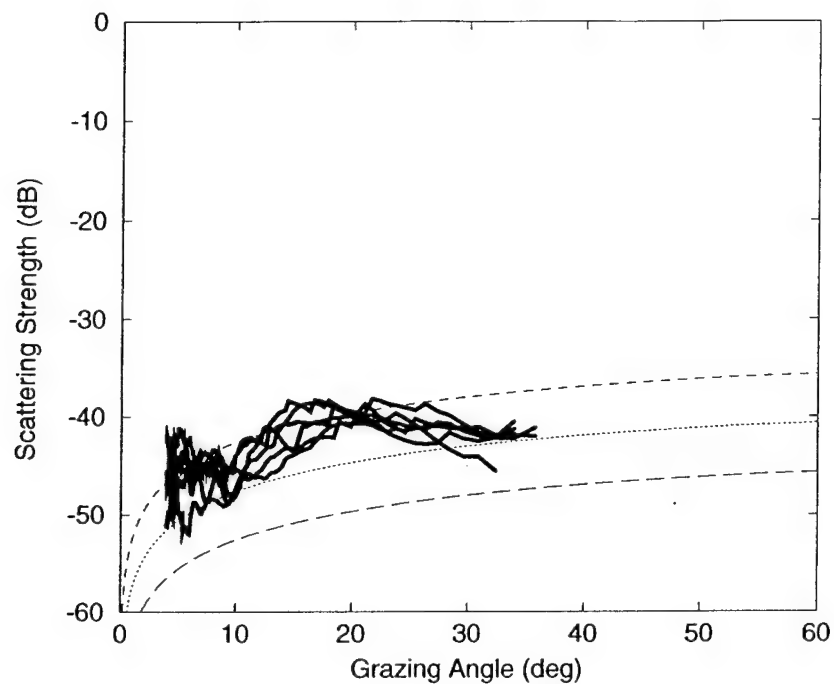
Fig. 11 — Bottom backscattering strength as a function of grazing angle for 3.5 kHz at Site 2. The dashed lines represent $\mu + 10 \log(\sin\theta)$ for μ = -35, -40 and -45.
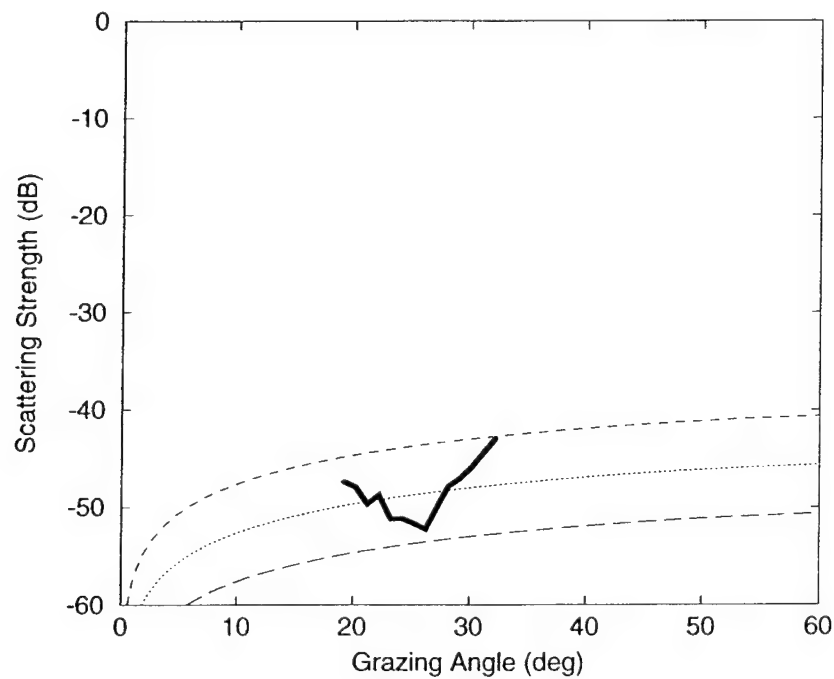

Fig. 12 — Bottom backscattering strength as a function of grazing angle for 4 kHz at Site 2. The dashed lines represent $\mu + 10 \log(\sin\theta)$ for μ = -35, -40 and -45.

Fig. 13 — Bottom backscattering strength as a function of grazing angle for 4.5 kHz at Site 2. The dashed lines represent $\mu + 10\log(\sin\theta)$ for $\mu = $ -35, -40 and -45.

Fig. 14 — Bottom backscattering strength as a function of grazing angle for 5 kHz at Site 2. The dashed lines represent $\mu + 10\log(\sin\theta)$ for $\mu = $ -35, -40 and -45.

Fig. 15 — Bottom backscattering strength as a function of grazing angle for all six frequencies from the MF band (2.5, 3, 3.5, 4, 4.5 and 5 kHz) at Site 2. The dashed lines represent $\mu + 10 \log(\sin \theta)$ for $\mu = $ -35, -40 and -45.

Fig. 16 — Bottom backscattering strength as a function of grazing angle for 400 Hz at Site F. The dashed lines represent $\mu + 10 \log(\sin \theta)$ for $\mu = $ -40, -45 and -50.
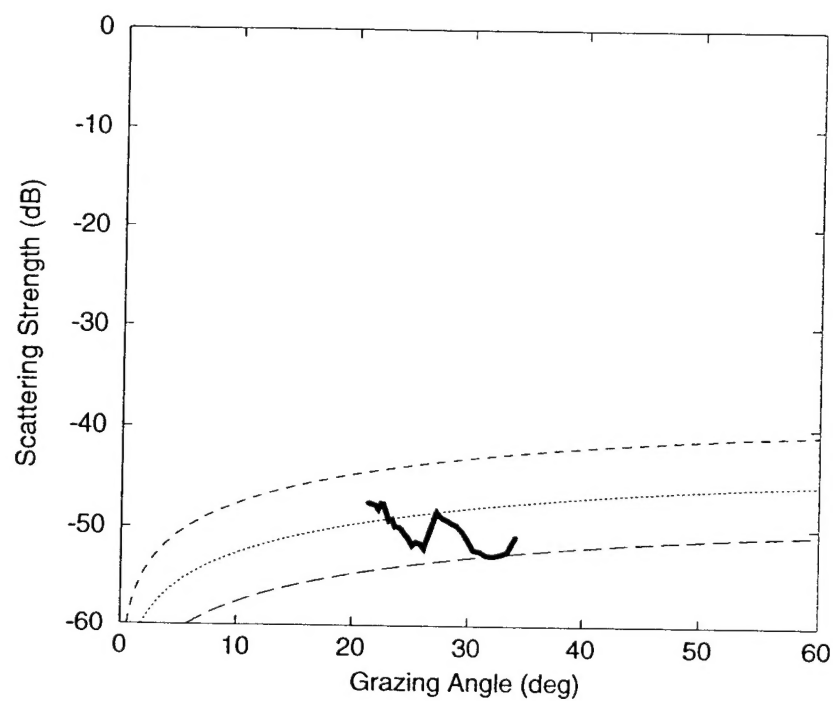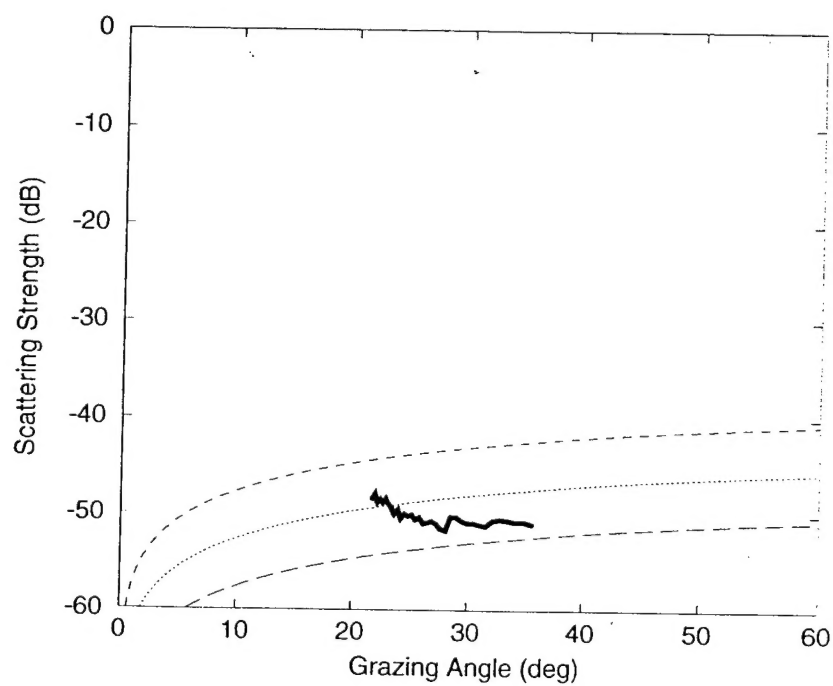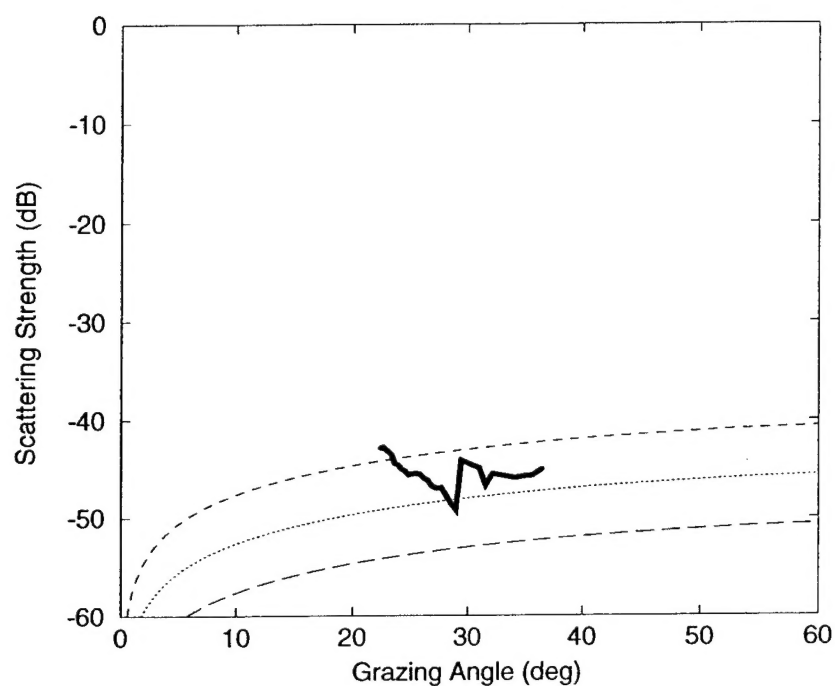
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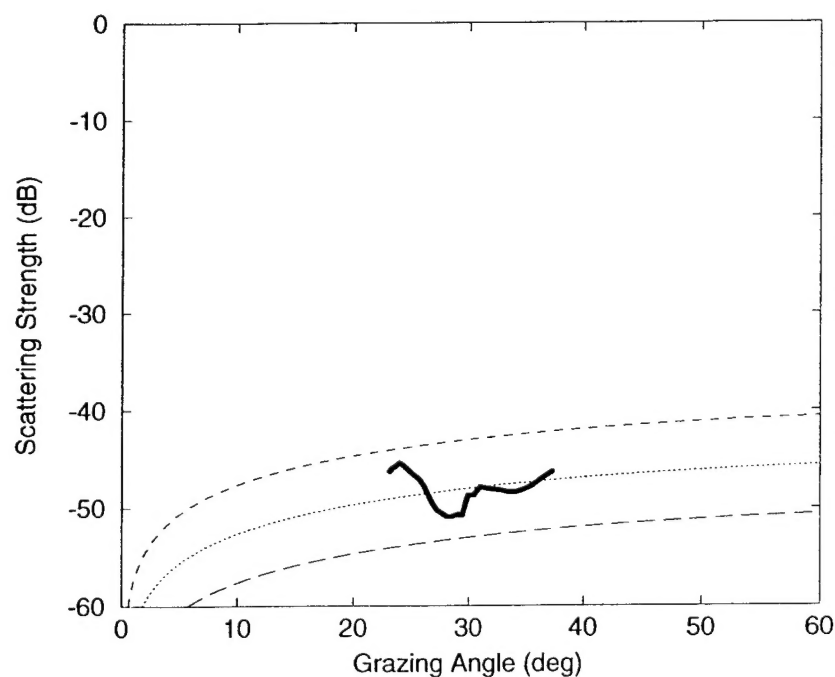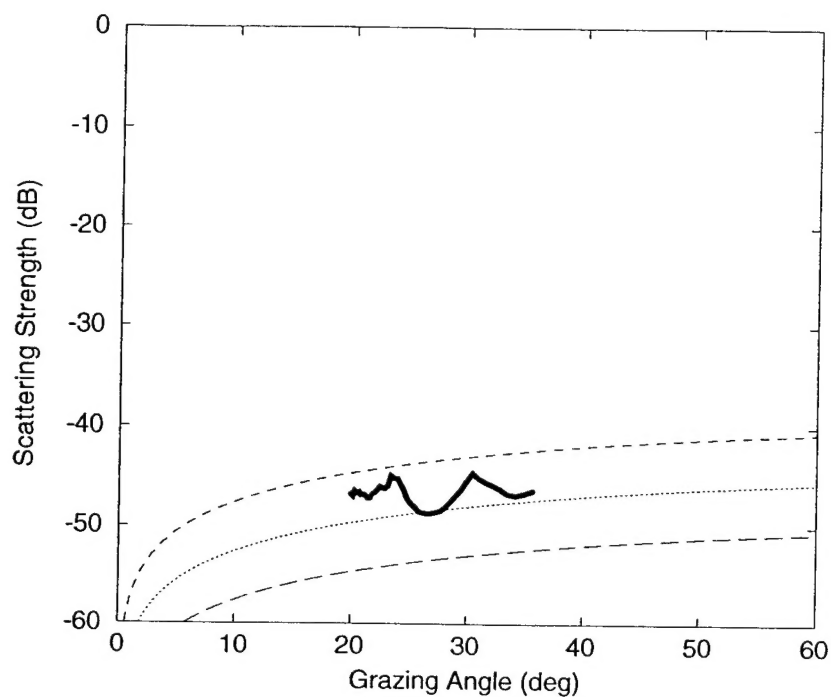

Fig. 18 — Bottom backscattering strength as a function of grazing angle for 600 Hz at Site F. The dashed lines represent $\mu + 10 \log(\sin \theta)$ for $\mu = $ -40, -45 and -50.

Fig. 19 — Bottom backscattering strength as a function of grazing angle for 700 Hz at Site F. The dashed lines represent $\mu + 10\log(\sin\theta)$ for $\mu = $ -40, -45 and -50.

Fig. 20 — Bottom backscattering strength as a function of grazing angle for 800 Hz at Site F. The dashed lines represent $\mu + 10\log(\sin\theta)$ for $\mu = $ -40, -45 and -50.

Fig. 21 — Bottom backscattering strength as a function of grazing angle for 900 Hz at Site F. The dashed lines represent $\mu + 10\log(\sin\theta)$ for $\mu = $ -40, -45 and -50.
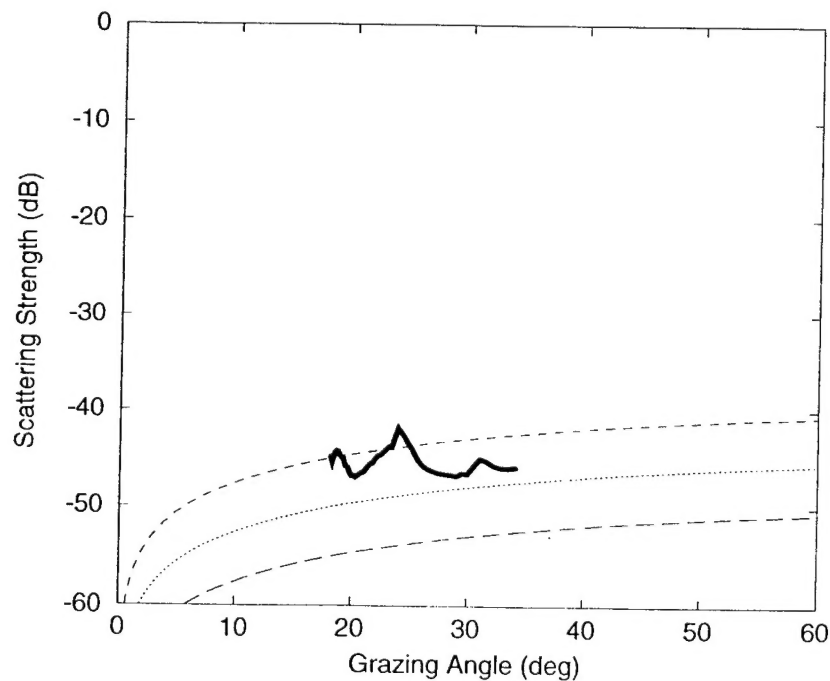

Fig. 22 — Bottom backscattering strength as a function of grazing angle for 1000 Hz at Site F. The dashed lines represent $\mu + 10\log(\sin\theta)$ for $\mu = $ -40, -45 and -50.
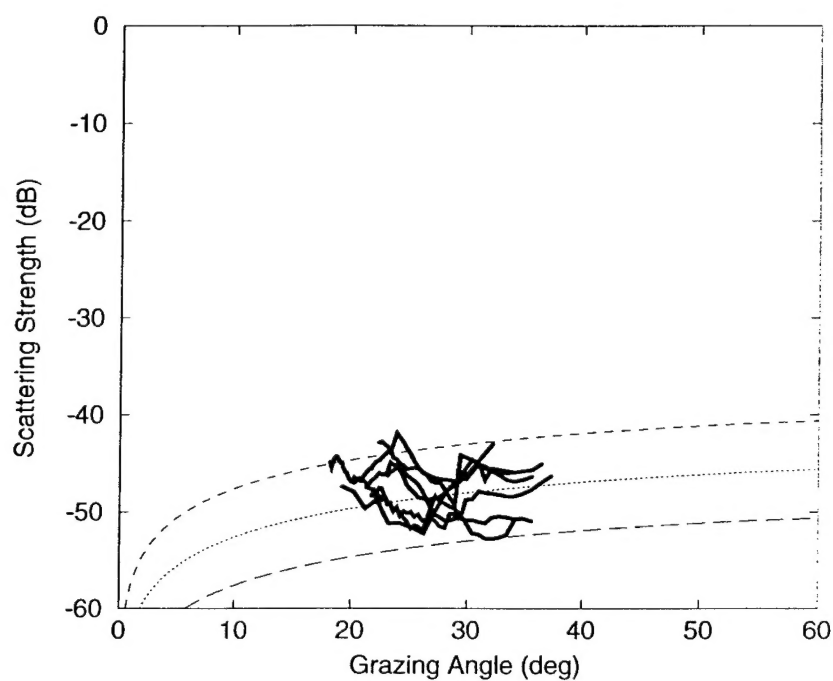
Fig. 23 — Bottom backscattering strength as a function of grazing angle for all seven frequencies from the LF band (400, 500, 600, 700, 800, 900 and 1000 Hz) at Site F. The dashed lines represent $\mu + 10\log(\sin\theta)$ for $\mu = $ -40, -45 and -50.